



# Bridging the nanogap electrodes with gold nanoparticles using dielectrophoresis technique

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## Abstract

We report the assembling of 20 nm gold nanoparticles into the nanogap electrodes by dielectrophoresis (DEP) technique. DEP was performed on electrodes with different gap size values. While the frequency and the applied peak to peak voltage were maintained at 1 MHz and 3 V, respectively, DEP time was varied in accordance with electrodes gap size. Interestingly, some novel assembling was observed during the dielectrophoresis process and the nanogaps were bridged by nanoparticles either forming ring shaped bridges or linear bridges. The assembling of nanoparticles in different form is attributed to the positive DEP effect. This effect is seen to be influenced significantly by the time parameter during which DEP was performed. Results show the promise of dielectrophoresis in controlled engineering of nanoparticles assembly.

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## 1. Introduction

Assembly of nanoparticles into nanogap electrodes has generated a considerable interest for the potential molecular electronics applications [1–6]. One of the most versatile techniques known till date which is used for the nanoparticles assembly is dielectrophoresis (DEP) [7–14]. The phenomena of DEP involves either ac or dc field gradient which causes the development of non-uniform electric field. The pioneering work by Pohl [7] provided the basic theory of DEP and its early applications. DEP can be understood by considering the simple picture of a dipole in a non-uniform electric field. The dipole will be at least partly oriented in the direction of the field gradient and hence one end of the dipole will experience stronger electric field

strength than the other. This results in a non-zero net force and the dipole is set in motion [7,9]. Due to its remarkable applications, DEP has drawn the attention of nanotechnologists and nanoscientists world wide for the assembling of different macroscopic particles like nanoparticles, nanowires, carbon nanotubes and living cells [3–6,15–18]. Out of these different macroscopic particles, DEP has been extensively studied for trapping gold (Au) nanoparticles by many research groups [2–6]. Khondaker and Yao [3] reported exciting results of assembling Au nanoparticles into nanogap electrodes. Barsotti et al. [4] demonstrated the optimized assembly of Au nanoparticles in the electrode gaps (15–150 nm) created by localized melting technique using DEP technique. However, these reports were mostly confined to single nanoparticle assembly. Though assembling of nanoparticles using DEP is well documented, but less attention has been paid on the bridging of nanoparticles into nanogap electrodes of varying size. In the present paper, we report the study of bridging the nanogap

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electrodes with Au nanoparticles via ac DEP technique. The DEP is performed on electrodes with different gap sizes and the influence of time on the assembling of nanoparticles in the electrodes gap is studied and analyzed.

## 2. Experimental

Standard electron-beam lithography (EBL) was used to fabricate the Au electrodes on the passivated silicon substrates. Four different electrodes geometry were patterned separately on passivated silicon substrates with electrodes gap sizes of 20 nm, 60 nm, 70 nm, and 100 nm, respectively. The details regarding the experimental set-up and the steps used for DEP are reported elsewhere [5]. Au nanoparticles of 20 nm diameter were purchased from British Bio Cell International and used at the as-purchased concentration ( $7 \times 10^{11}$  particles/ml). Prior to DEP assembling, the chip was passed through a cleaning process such as  $O_2$  plasma cleaning and rising in ethanol. A micropipette was employed to take an approximately 1  $\mu$ l drop of aqueous nanoparticles solution for the DEP processing. Finally, the bridging of Au nanoparticles in the nanogap electrodes was examined by SEM after DEP processing.

## 3. Results and discussion

The present work is aimed to see the influence of time on the assembling of nanoparticles (20 nm) into nanogap electrodes of different sizes i.e. 20 nm, 60 nm, 70 nm, and 100 nm. In our previous study we had optimized the con-

trolled assembly of single Au nanoparticles (20 nm) into electrodes with 20 nm gap via ac DEP technique, and the assembly was achieved at optimized DEP parameters such as the magnitude of applied ac frequency of 1 MHz, applied peak to peak voltage of 2 V, and the time of 2 s during which non-uniform field is active. It was also concluded that under such DEP parameters minimum number of nanoparticles could be trapped in the nanogap (20 nm) of the electrodes. Therefore, in the present study, the experiments were performed at a fixed applied frequency of 1 MHz and the applied peak to peak voltage was restricted to a value little higher than the optimized value of 2 V. The third parameter i.e. time was varied and its influence on the assembling of nanoparticles was studied.

Fig. 1 shows the SEM images of the assembly of nanoparticles into nanogap electrodes. All the assembly was carried out at fixed frequency of 1 MHz and applied peak to peak voltage of 3 V. Fig. 1a, b, c, and d shows the assembly observed when the DEP was performed on electrodes with gap size values of 20 nm, 60 nm, 70 nm, and 100 nm, respectively. For 20 nm gap electrodes, the time during which DEP was performed was maintained at 3 s, which is slightly higher than the optimized value of 2 s, where single nanoparticle assembly was observed [5]. This observed assembly is in agreement with the fact that at higher assembling time more number of nanoparticles aggregate near the tip of the electrodes [5]. Fig. 1b shows the assembly of nanoparticles into 60 nm gap electrodes when DEP was performed for 10 s. In this case, with an increase in DEP time more number of nanoparticles (on an average

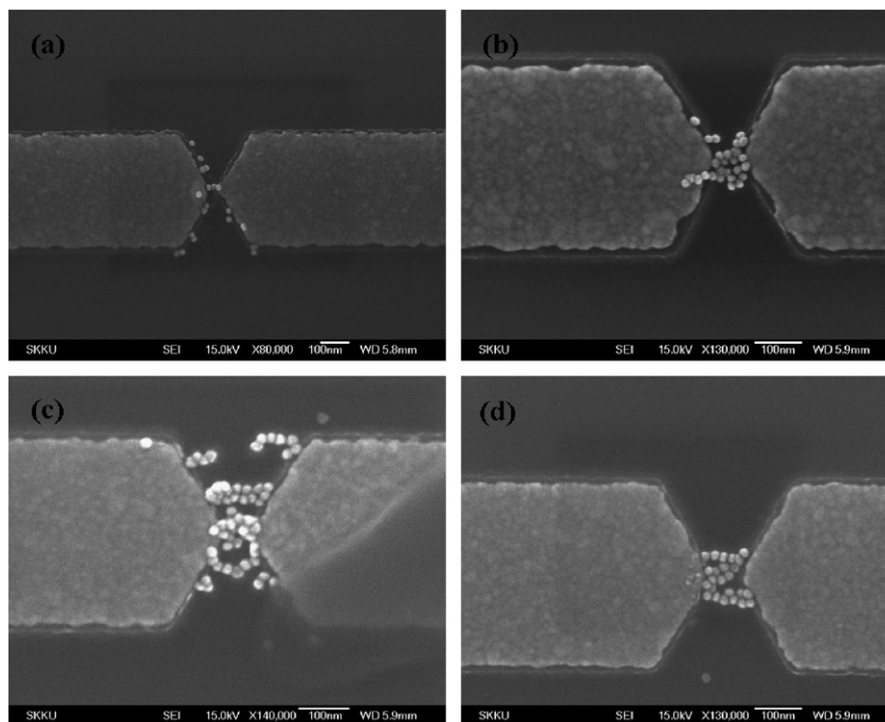


Fig. 1. SEM images of the assembling of nanoparticles in nanogap electrodes when DEP was performed as function of time at a fixed frequency and applied peak to peak voltage of 1 MHz and 3 V, respectively. The images correspond to electrodes with different gap sizes of (a) 20 nm; (b) 60 nm; (c) 70 nm; and (d) 100 nm. The corresponding time values were 3 s, 5 s, 20 s, and 10 s, respectively.

~15) is seen to aggregate near the tip of the electrodes. With an increase in DEP time, there is possibility of aggregation of nanoparticles in the region of high electric field (positive DEP), which would cause the flow of large current through these nanoparticles, and ultimately their melting and aggregation. Therefore, with increase in DEP time, nanoparticles are seen in the region near the tip of electrodes. However, when the DEP was performed for 70 nm electrodes gap at the DEP time of 20 s, nanoparticles were seen to bridge the gap between the electrodes in a ring shaped manner (Fig. 1c). Such ring shaped nano-bridges were reproducible and it was found that the DEP time was the crucial factor to produce such rings. With further increase in DEP time, more particles were found to aggregate near the tip and in its vicinity. It may be noted that at higher DEP time (<20 s) no such ring formation was observed. To see the influence of lowering the DEP time on a wider gap between the electrodes, the experiments were further carried out by performing DEP on the electrodes with gap size of 100 nm and DEP time value of 10 s. It was noticed that linear bridges extending from one electrode to another electrode were seen to form. It is important to mention that such parallel chains or bridges of nanoparticles disappeared and reshaped into the clusters of nanoparticles near the tip of electrodes when DEP time was increased to 20 s.

Therefore, it may be concluded from the present observations that nano-bridges of various kinds could be achieved by controlling the time during which DEP is performed. In the present case, ring shaped nano-bridges and linear bridges were observed when DEP was performed for different time values. Moreover, nano-bridges of various other kinds can be envisaged by varying other DEP parameters such as frequency and applied voltage also.

#### 4. Conclusion

Dielectrophoresis of 20 nm gold nanoparticles was performed on the electrodes of varying gap sizes. The assembling of nanoparticles was performed at fixed applied frequency of 1 MHz and peak to peak voltage was maintained at 3 V. The nanoparticles were seen to assemble in the gap between the electrodes forming different shapes

such as ring and linear bridges depending on the gap size and the time during which DEP was performed. Results show the promise of DEP to engineer the assembly of nanoparticles to create novel bridges by controlling the DEP parameters.

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